Spin-Isospin Modes in Heavy-Ion Collisions
II: Transport Simulations[*]

Johan Helgesson[†] and Jørgen Randrup

Pions, nucleons, and Δ isobars couple strongly in the nuclear medium and the resulting spin-isospin modes may affect the transport properties. We have made transport simulations incorporating in-medium pion dispersion relations, partial Δ widths, pion reabsorption cross sections, $NN \leftrightarrow \Delta N$ cross sections, and Δ spectral functions. These in-medium quantities have been calculated microscopically from the $\pi + NN^{-1} + \Delta N^{-1}$ model presented in [1] and incorporated into the transport formalism of Li and Bauer [2] by a local density approximation. The medium-modified simulations show strong effects on properties not directly observable during the collision process, such as pion and Δ production and reabsorption rates. However, the π and Δ populations are rather insensitive to the specific cross sections, because chemical equilibrium between these degrees of freedom is established rather quickly. Moreover, there are only minor effects on the spectra of the emitted pions, as is reasonable since most of the emitted pions are produced at the surface where the density is low and the in-medium effects are correspondingly small.

It is reasonable to expect that the in-medium properties incorporated into the transport treatment by the local density approximation lead to larger effects than might occur in a real nuclear collision. In such a collision the volume and time for the interactions are finite and it might be that, for example, collectivity is developed to a smaller degree than in infinite nuclear matter at equilibrium. Another uncertainty in the present treatment is that we, also at high densities, have used interactions and coupling constants, that are known in vacuum or at low densities.

For this reason we have chosen to present results based on two different microscopic input (with some properties quite different). Thus we have illustrated which quantities in the transport treatment depend sensitively on the input, and which ones that are more robust.

Form factor choice FF1 with the chosen parameter set leads for high densities to pion condensation effects in the microscopic calculations (manifested in a large width for Δ decay to low energy NN^{-1} modes). While these effects probably are absent in a real nuclear collision, we have chosen to implement them into the transport treatment to study what effects remain after transport simulations. Although our transport treatment becomes very crude when we incorporate microscopic results containing effects of onset of pion condensation, it is notable that the effects on pion observables are very small, even though very strong effects are found on low mass Δ's. Note also that the pion condensation effects for FF1 does not rule out this form factor choice, since the onset of pion condensation could be pushed up to higher densities by several means, for example by using an extended ΔN^{-1} model or by using density dependent g' parameters.

In an energetic nucleus-nucleus collision also other particles, not considered in this work, are produced in multi-step processes where Δ's and pions act as intermediate particles. Thus, the inclusion of medium-modified Δ's and pions could be important when studying kaon and dilepton spectra, for example, in order to correctly understand signatures of in-medium modifications of vector meson masses due to chiral restoration.

[1] J. Helgesson, J. Randrup, Ann. Phys. 244 (1996) 12; J. Helgesson, J. Randrup, Nucl. Phys. A597 (1996) 672.
[2] B.A. Li and W. Bauer, Phys. Rev. C44 (1991) 450.